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ACTIVE MATERIAL WITHIN HYDROGEL MICROBEADS

Field of the Invention

The invention relates broadly to immobilization and release of active material within hydrogel microbeads. The hydrogel microbeads can be used to immobilize water soluble and water insoluble actives such as oils, fragrances, lubricants, and agricultural chemicals such as pheromones, herbicides, insecticides and pesticides.

Background

Methods of eliminating unwanted pests from orchards, crops and forests frequently entail the use of organophosphate insecticides. Alternative methods involve insect mating disruption, where insect pheromones are used to control pests and protect agricultural crops. In insect mating disruption methods, the mating pheromone plume of a female insect is typically masked with other pheromone point sources. This reduces the likelihood of a male insect finding a female, and subsequently disrupts and reduces larvae production. The insect population of the next generation is thus decreased, as well as potential crop damage.

Conventional sprayable pheromone formulations are generally provided in liquid filled microcapsules containing an active. Typically, the microcapsules have a polyurea membrane that can be formed using an interfacial process involving an isocyanate and an amine. Microencapsulation by this method has been described for example in U.S. Patent 4,487,759 (Nesbitt *et al.*, 1984). These polyurea membranes allow actives to be released into the atmosphere for up to a total of 2-3 weeks for most insect pheromones.

Use of interfacial condensation to encapsulate substances such as pharmaceuticals, pesticides and herbicides is taught in U. S. Patent No. 3,577,515. The encapsulation process involves two immiscible liquid phases (typically water and an organic solvent), one being dispersed in the other by agitation, and the

subsequent polymerization of monomers from each phase at the interface between the bulk (continuous) phase, and the dispersed droplets. Polyurethanes and polyureas are materials suitable for producing the microcapsules. The microcapsules comprise a polymeric sphere and a liquid center, ranging from 30 micron to 2 mm in diameter, depending on monomers and solvents used.

Highly viscous and thickened hydrogels have been used to deliver pheromones, fragrances and other non-water soluble actives. U.S. Patent No. 4,755,377, for example, describes a process of encapsulating perfume or fragrant material within an aqueous-based gel composition. The resulting material is in the form of a highly viscous semi-solid. U.S. Patent No. 5,645,844 describes the use of chitosan paste for delivery of pheromones to disrupt insect mating, where the material can be dispensed by an apparatus such as a caulking gun. Due to their thickness and high viscosity, these materials, however, are generally unsprayable compositions.

Most hydrogels are safe and non-toxic to humans. Hydrogels have been used for encapsulation of biological materials whereby the formulation is non-lethal to the viability of cells, proteins, and related materials. U.S. Patent No. 4,689,293, describes the process of encapsulating living tissue or cells in alginate beads. The encapsulation shell permits the passage of materials and oxygen to the cells and permits the diffusion of the metabolic by-products from the gel.

Summary of the Invention

A method of delivering active material using a plurality of microbeads suspended in solution is provided, where the microbeads comprise a hydrophilic matrix having droplets of active material entrained therein. Furthermore, the matrix is capable of immobilizing a broad spectrum of active materials, either water soluble or non-water soluble. In one aspect of the invention, the hydrophilic matrix may be made from a naturally occurring material to provide an environmentally friendly microbead.

In another aspect of the invention, the active entrained in the matrix diffuses from the hydrophilic matrix and is released into the environment over an extended period.

In yet another aspect, the microbeads are capable of re-hydrating after an initial dehydration and release of active. Thus, the release and longevity of the active can be controlled by adjusting the humidity of the environment in which the microbeads have been delivered.

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Brief Description of the Drawings

FIG. 1 is a cross-sectional illustration depicting a preferred embodiment of a microbead of the invention.

FIG. 2 is a graph from data obtained in EXAMPLE 6.

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Detailed Description of the Preferred Embodiments

In view of the increasing awareness of insecticide toxicity to humans and other environmental concerns, it would be advantageous to provide an active delivery system having an extended release life and having a hydrogel material in order that it be non-toxic and bio-degradeable. It would also be advantageous to provide a system for sprayable long lasting active delivery that would be applicable to a broad spectrum of actives thereby eliminating the issue of reactivity of the active with one of the membrane components.

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The present invention involves immobilizing active(s) within a hydrogel matrix in a microbead format. Furthermore, the invention provides a method of controlling release of active(s) by cyclically hydrating and re-hydrating the microbeads. The microbeads of the invention comprise a matrix forming material, and is preferably substantially spherical. The matrix forming materials of the present invention are hydrophilic and water soluble. Entrained or finely dispersed within the matrix are micro-sized droplets of active material. Active materials that can be immobilized within the hydrogel microbeads include aldehydes, esters, alcohols, epoxy compounds, ethers, ketones, or combinations thereof. This invention is particularly advantageous for delivery of reactive ketones in which the double bond of the carbonyl group is conjugated with one or more double bonds, for example acetophenone where the carbonyl group is conjugated with double bonds of the aromatic ring.

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Conventional active delivery systems (such as for delivery of pheromone) generally involve polyurea or polymethyleneurea encapsulation, where interfacial polymerization or *in situ* polycondensation occurs to provide microencapsulated products, respectively. These systems however, are typically limited to encapsulation of water non-soluble and/or non-alcohol active materials, due to, for example, the reactivity of alcohol with the isocyanate contained in the polyurea membrane. Surprisingly, it has been found that hydrogel microbeads made from water soluble materials provide sufficient immobilization of oil soluble actives and alcohol actives such that the active can be delivered and sprayed by conventional techniques. Furthermore, rather than relying on interfacial encapsulation, the hydrogel microbeads entrap micro-sized droplets of active material within the hydrophilic matrix. This matrix advantageously imparts the capability of the hydrogel microbeads to immobilize oil-soluble active materials and minimizes the risk of undesired reactivity between the active and its immobilizer. Thus, immobilization of active materials by use of the microbeads of the invention does not render the immobilized material inert or ineffective.

A further surprising benefit from immobilizing active ingredients in hydrogel microbeads is the ability of the hydrogel to “swell” under humid conditions and shrink under dry conditions. As used herein, “swell” is descriptive of the behavior of a microbead, wherein the size (volume) is enlarged (increased) due to absorption of water. This is likely due to the hydrophilic nature of the matrix forming materials used to immobilize the active material.

In the presence of humidity, the hydrogel microbeads are surprisingly found to be capable of absorbing moisture, rehydrating, and consequently releasing active material contained within the matrix. This behavior can be cyclical. Thus, by controlling the humidity (or dryness) of the ambient air, the release rate of active material from the microbeads can be controlled such that specific periods of release can be generally predicted. It is therefore possible with the present invention to release the active material on demand from the microbead. Release on demand, or “smart release,” can be advantageous in those instances where release is preferred at certain times. The microbeads’ ability to further release active from the matrix and may increase the longevity of releasing effective amounts of active

material. Preferably, the microbeads are delivered to an intended environment in effective amounts to obtain the desired effect. For example, microbeads having pheromones entrained therein, are preferably delivered to a desired area in amounts such that mating disruption is effected and release is accomplished for more than 4 weeks, more preferably, the microbead can release for more than about 6 weeks; and most preferably more than about 8 weeks.

During the drying process (i.e dehydration) a surface film layer will form as a result of water evaporation from the matrix. Both initially and during use, the microbeads are characterized by a large surface area to volume ratio, which helps maintain the rate of diffusion of the active material during use. Thus, it has been found that microbeads made according to the method of present invention provide excellent delivery systems as they are capable of releasing active material for extended periods. Furthermore, since the active is dispersed within a water-based matrix, additional protection from environmental conditions (i.e., UV) can be provided.

Although it has been found that microbeads of the invention can be made having a diameter of up to about 5 millimeters (mm), it is preferred that the microbeads be between about 1 micrometers (μm) to about 1000 μm and more preferably between about 1 μm to about 500 μm in diameter to ensure that the microbeads are easily sprayable from conventional spray nozzles. Most preferably, to ensure minimal clogging in conventional nozzles, the microbeads are less than about 400 μm in diameter. It is contemplated, however, that with the advent of larger spray nozzles not currently used in the industry, the microbeads can be provided in much greater diameters.

For spraying applications, particularly aerial spraying, it is desirable that the microbeads be capable of remaining suspended in solution (e.g., water) to ensure that the microbeads do not sink, settle, or coagulate in the suspension. A uniform suspension ensures an even spray coverage. Preferably, the microbeads of the invention are able to remain in suspension, thus minimizing if not eliminating the need to agitate during application and optionally storage. Various suspension aids can also be included in the suspension containing the microbeads of the

invention. Examples of suitable suspension aids include rhamus gum, xanthum gum, gellan gum, pectin, and gum arabic.

Owing to the handling to which the microbeads may be subjected, it is preferable that the microbeads of the present invention should be somewhat elastic, and not frangible. For example, typical atomization of a suspension during a spray application will force the suspension through two rotating perforated discs that are immediately upstream of the discharge nozzle. Sufficient elasticity of the microbeads minimizes physical damage to the microbeads as they pass through the discs.

The microbeads of the present invention comprise a matrix forming material and active material. Referring now to FIG. 1, a preferred embodiment is shown, where a plurality of active material droplets **10** are entrained within hydrophilic matrix **12**. As seen in FIG. 1, active material droplets **10** are preferably located between and within matrix **12**, where matrix **12** provides an immobilizing network around the droplets. The degree and extent of agitation as well as the type of surfactant used to form the microbeads can affect the size and the dispersity of the pheromone droplets within the microbead's matrix. Droplets **10** are preferably can range in size between about 0.01nm to about 200,000nm in diameter. More preferably, the droplets are between about 1 to about 1000nm in diameter.

The matrix-forming material useful in the present invention are biocompatible, water-soluble, have pendant functional groups, and complex with ions (e.g., polyvalent cations and/or anions) to form hydrogels. Functional groups of the matrix forming material include for example, carboxyls, hydroxyls, primary or secondary amines, aldehydes, ketones, esters, and combinations thereof. Preferably the hydrophilic matrix-forming material can be made from naturally occurring polysaccharides, such as alginates, chitosans, gums, agars, carrageenans, or the matrix can be made synthetic, water soluble monomers, oligomers or polymers, such as, for example, polyvinyl alcohol, poly(N-isopropylacrylamide), acrylamides, acrylates, methacrylates, or combinations thereof.

Suitable naturally occurring polysaccharides include the water-soluble salts of alginic, pectic and hyaluronic acids, the water-soluble salts or esters of

polyglucuronic acid, polymanuronic acid, polylygalacturonic acid and polyarabinic acid, and gum kappa-carrageenan. The preferred polysaccharides are the ammonium, magnesium, potassium, sodium and other alkali metal salts of alginic acid, and the most preferred polysaccharide is sodium alginate.

“Alginate” is the general name given to alginic acid and its salts. Alginates are composed of D-mannosyluronic (mannuronic - “M”) and L-gulopyranosyluronic (guluronic - “G”) acid residues. The ratio of mannuronic to guluronic acid residues is known as the M:G ratio. The alginate used to immobilize active droplets should be carefully selected to ensure proper microbead formation, ensure the stability of the microbeads during storage and delivery applications, and ensure that the microbeads are able to shrink and swell appropriately to deliver the desired active material over an extended period of time (preferably 4-6 weeks). Preferably, an alginate is chosen such that the matrix formed is sufficient in strength to withstand the shear forces (conditions) placed upon the microbeads during application via a spray nozzle - i.e., the microbeads are resistant to rupture during the spray application.

For strength and stability of the microbeads, it is desirable to choose the molecular weight and M:G ratio of the alginate to obtain preferred properties of the ultimate matrix. Although alginates high in mannuronic acid are generally useful for thickening applications, whereas alginates with a high level of guluronic acid are often used for forming gels, both alginate categories (individually or a mixture thereof) are suitable for the microbeads of the invention. A preferred alginate that imparts strength and rupture resistance is an alginate that has a high level of guluronic acid, e.g., greater than about 30 percent by weight. Alginate compositions with excessive levels of mannuronic acid could result in less stable and less rigid microbeads than high guluronic acid gels. However, high mannuronic acid alginates impart to the microbeads the capability of swelling and absorbing more water than microbeads of high guluronic acid content. Thus, a careful balance of the advantages imparted by each of M and G residues should be considered when choosing a suitable alginate.

It has been surprisingly found that alginates preferably having a molecular weight in the range of about 100,000 kg/mol to about 2,500,000 kg mol, more

preferably about 200,000 kg/mol to about 1,500,000 kg/mol. Furthermore, the alginates preferably have an M:G ratio in the range of about 0.2 to about 3.5; more preferably about 0.3 to about 1.85.

Preferred alginates that have a high level of guluronic acid, for example are alginates from the algae *Laminaria hyperborea*, stem, whole plant or frond. Preferred alginates with high levels of mannuronic acid include *Ascophyllum nodosum*, for example.

Gel matrices formed by crosslinking polysaccharides bearing pendant carboxylate groups are also useful as a preferred class in the present invention. These compounds are composed of water-insoluble alginates which include, with the exception of magnesium and the alkali metal salts, the group II metal salts of alginic acid. The water-insoluble alginate gels are typically formed by the chemical conversion of water-soluble alginates in an aqueous solution into water-insoluble alginates. This conversion usually is accomplished by the reaction of a water-soluble alginate with polyvalent cations released from a soluble di- or trivalent metal salt.

Water-soluble alginates can include the ammonium, magnesium, potassium, sodium, and other alkali metal salts of alginic acid. Water-insoluble di- or trivalent metal salts suitable for the present invention should satisfy two requirements: (1) that the water-insoluble metal salt contain a di- or trivalent metal ion capable of complexing with the pendant carboxylate groups of the water-soluble polysaccharide to cause the formation of a water-insoluble polysaccharide gel; and (2) that the water-insoluble metal salt reacts with a water-soluble acid to form a water-soluble metal salt.

A common and suitable alginate gel is composed of calcium alginate.

Sources for the crosslinking calcium ions used in the formation of alginate gels include, for example, calcium carbonate, calcium sulfate, calcium chloride, calcium phosphate, calcium tartrate, calcium nitrate, and calcium hydroxide. Other acceptable crosslinkers may include lanthanum chloride, ferric chloride, cobaltous chloride, as generally are other compounds with multivalent cations, such as calcium (Ca^{++}), copper (Cu^{++}), barium (Ba^{++}), strontium (Sr^{++}) and the like.

The time of gelation of the calcium alginate gels can be accomplished by regulating the concentration of free calcium ions in the solution. Typically the concentration of free calcium ions is controlled by manipulation of the ionization rate of the calcium salt and/or by the inclusion of other compounds in the solution which react with the free calcium ions.

It has been advantageously found that it is possible to immobilize a wide range of active materials, including non-water soluble materials as well as alcohols.

Preferred active materials entrained in the matrix are partially water-miscible organic molecules of compounds that have a molecular weight in the range of between about 100 to about 400, preferably between about 150 to 300. The compounds contain a heteroatom that confers some degree of water-miscibility. For many compounds of interest the sole heteroatom is oxygen, and there may be up to three heteroatoms per molecule in, for instance, hydroxy-substituted or keto-substituted carboxylic acids. Unsubstituted carboxylic acids of course contain two oxygen atoms and simple aldehydes, ketones and ethers contain only one oxygen atom. Compounds that contain nitrogen and/or sulphur atoms are also of interest.

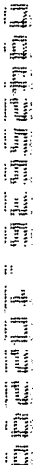
Of particular interest are biologically active compounds. For purposes of the present invention, the term "biologically active" means materials that affect the life processes of organisms. Materials that are biologically active include herbicides, pesticides, pharmaceuticals, and semiochemicals, including naturally and artificially produced pheromones and synthetic pheromone analogs. Materials of this nature that are of particular interest are those materials that interfere with a life process essential to the survival of a target pest.

The method of the invention can be used to immobilize pheromone with functional groups such as acetates, aldehydes, ketones, alcohols, ethers, esters, and epoxies. Pheromones may be defined as compounds which, when naturally produced, are secreted by one member of an animal species which can influence the behavior or development of another member of the same animal species. Pheromones generally are species-specific and therefore the application of pheromones for insect behavior modification has minimal effect on non-target

pests. Pheromones supplied for modification of insect behaviour interfere with the "mate finding process" by releasing point sources of pheromone, which may compete with or camouflage the pheromone plume of a female. This latter type of action differs from chemical insecticides or insect growth regulators or hormones, in that pheromones target future generations of insects, not present ones. As pheromones are very species-specific and are used only in small quantities, their use is more environmentally acceptable than broadcasting of pesticides.

Many pheromones have an ester terminal group, for example acetate or formate group. Typically these substances are water-immiscible and incorporation of them into microcapsules by known methods presents no particular problem. Many other pheromones have an aldehyde or an alcohol terminal group. In general, these are partially water-miscible and potentially reactive with the reactants used to encapsulate by prior, conventional methods. In particular, it is difficult to achieve high degrees of encapsulation of materials that have some degree of water solubility, as the material partitions between the small amount of organic solvent and the relatively larger amount of water that constitutes the continuous phase. Furthermore, these compounds can be expected to react with the reactants used to encapsulate. Aldehydes and ketones react with amines to form aldimines and ketimines, respectively. Alcohols, carboxylic acids and mercaptans react with isocyanates. Epoxy compounds react both with amines and with isocyanates. Thus, the present invention overcomes the limitation of delivering partially water-miscible substances such as alcohols, aldehydes, carboxylic acids, ketones, ethers, including epoxy compounds, and mercaptans.

Pheromones useful in the inventive microbeads are preferably insect pheromones. In describing the structure of the a pheromone, the following notation is used: the type (E (trans) or Z(cis)) and position of the double bond or bonds are given first, the number of carbon atoms in the chain is given next and the nature of the end group is given last. To illustrate, the pheromone Z-10 C19 aldehyde has the structure;



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Other active materials useful in discouraging approach of animals include essences of garlic, putrescent eggs and capsaicin.

Other active compounds that can be included in the microbeads of the invention include perfumes, fragrances, flavouring agents and the like.

5 Optionally, oil absorbents can be incorporated into the active droplets. These absorbents can help retain the active droplets within the microbeads, resulting in longer lasting formulations. Clays and starches could alternatively be used for this purpose.

10 The concentration of active material in the microbeads of the invention should be at a level such that the matrix forming material can still provide a strong, rupture resistant network and deliver an effective amount of the active material to the environment to which it is intended. Thus, the active material is preferably present in an amount between about 0.1 wt % to about 60 weight percent (wt%) of the total weight of the microbead. More preferably, the amount of active material
15 is present in the microbead at between about 0.2 wt% to about 40 wt %; and most preferably between about 0.3 wt% to about 20 wt %.

20 The microbeads of the present invention are preferably delivered in suspension in aqueous or solvent-based solutions. For environmental and biologically-friendly reasons, it is preferred that aqueous suspensions be used. Suspension aids are preferably included in the suspension formulations to ensure the microbeads remain suspended in solution.

25 Preferably, the suspension solution is substantially free of monovalent cations, such as sodium, to avoid degradation or breakdown of the microbeads. In a preferred aspect, a concentration of approximately 50 millimolar of a crosslinker such as calcium chloride is maintained in a stored solution comprising the microbeads of the invention.

30 Optionally, adhesive material can be included in the compositions of the invention to assist in retention of the microbeads to an intended substrate. The adhesive material can be provided in various forms, such as for example, latex or a tacky microspheres. Adherent properties imparted to the hydrogel microbeads should result in the microbeads being able to still retain their suspended state and minimize aggregation or coagulation in the aqueous suspension. Furthermore, any

adhesive material used to impart adherent properties should not affect the integrity of the particles; it should not dissolve or weaken the microbead(s).

A suitable adhesive material that may be included in the compositions of the invention is adhesive latex. The adhesive latex may be any suitable water-dispersible adhesive available in the art. In the agricultural business, such latex compositions are often called stickers or spreaders. Stickers are used to help non-encapsulated agriculture chemicals adhere to plants. Spreaders are used to help disperse non-encapsulated agriculture chemicals on application. Preferred adhesives are acrylate-based adhesives. One suitable latex is available from Rohm & Haas under the trade designation COMPANION. Another is available from Deerpoint Industries under the trade designation DPI S-100 (a proprietary sticker/spreader). Examples of such adhesives are polymers made from the "soft" monomers such as n-butyl acrylate, isooctyl acrylate, or the like, or copolymers made from a soft component, such as isobutylene, n-butyl acrylate, isooctyl acrylate, ethyl hexyl acrylate, or the like; and a polar monomer such as acrylic acid, acrylonitrile, acrylamide, methacrylic acid, methyl methacrylate or the like. Non-spherical polyacrylate adhesives are commercially available, for example, as the Rohm and Haas RHOPLEX line of adhesives. Preferably, the non-spherical polyacrylate adhesive is present in an amount of about 10-35% by weight of the total suspension.

Tacky microspheres of adhesive may alternatively be used to help adhere the hydrogel microbeads of the invention to an intended substrate. The tacky microspheres have sufficient adhesive properties to provide the desired adhesive function, yet there is no danger of completely coating the microbead which may lead to potentially inhibiting the release characteristics of the microbead. The combination of microbeads and tacky microspheres may be applied without the need to modify the orifices of conventional sprayers with minimal clogging or plugging problems. Furthermore, the incorporation of tacky (adhesive) microspheres to the (formulation) suspension of microbeads allows the microbeads' surfaces to become tacky. The beads can therefore stick to intended surfaces, such as, foliage and branches, for example. The adhesive microspheres, especially if they are hollow, may also absorb some of the active material into its

own body, thus providing a second mechanism of release of the active material. This could result in an overall alteration, preferably an enhancement, of the release profile.

5 Preferably, the adhesive material is an acrylate- or methacrylate-based adhesive system comprising infusible, solvent dispersible, solvent insoluble, inherently tacky, elastomeric copolymer microspheres as disclosed in U.S. Pat. No. 3,691,140. Alternatively, this adhesive composition may comprise hollow, polymer, acrylate, infusible, inherently tacky, solvent insoluble, solvent dispersible, elastomeric pressure-sensitive adhesive microspheres as disclosed in 10 U.S. Pat. No. 5,045,569. Other suitable adhesives are the tacky microspheres having pendant hydrophilic polymeric or oligomeric moieties that are disclosed in U.S. Pat. No. 5,508,313.

15 Alternatively, the adhesive comprises between about 60-100% by weight of hollow, polymeric, acrylate, inherently tacky, infusible, solvent-insoluble, solvent - dispersible, elastomeric pressure-sensitive adhesive microspheres having a diameter of at least 1 micrometer, and between about 0-40% by weight of a non-spherical polyacrylate adhesive. The hollow microspheres are made in accordance with the teaching of European Patent Application 371,635.

20 The compositions of the present invention may also include one or more adjuvants including, for example, gelling aids, preservatives, dyes, humectants, UV protectants, fixatives, emulsifiers, extenders, and freeze/thaw stabilizers such as polyhydric alcohols and their esters. These materials are present in an amount effective to achieve their extended function, generally less than about 5% typically less than 2%, by weight of the composition.

25 Incorporation of a light stabilizer can be included in the microbeads of the invention. Suitable light stabilizers include the tertiary phenylene diamine compounds disclosed in Canadian Patent No. 1,179,682, the disclosure of which is incorporated by reference. The light stabilizer can be incorporated by dissolving it, with the active, in a water-immiscible solvent. Alternatively, a light stabilizer can 30 be incorporated in the microbeads as taught in Canadian Patent No. 1,044,134, the disclosure of which is also incorporated by reference.

The process of making the microbeads of the invention, preferably comprises, initially, the formation of a microemulsion and the dispersion of the active material in the hydrogel material. The microemulsion is then mechanically atomized to create substantially spherical droplets which are subsequently gelled (hardened) to form a hydrogel microbead having an active material dispersed therein.

In a preferred method of making the microbeads of the invention, an emulsion of an oil active within a water soluble solution comprising a hydrogel is first formed. This emulsion is then followed by a mechanical microbead forming step that can be performed by, for example, spray method or emulsification. The droplets are then hardened or cured either by chemical means (i.e., polymer cross-linking) or by non-chemical means (i.e., temperature, pH, pressure). The resulting microbead is a hydrogel microbead, having greater than about 30% water initially, and the active would be finely dispersed and entrained within the water-polymer matrix. The size of the microbeads is generally governed by the intrinsic properties of the emulsion solution, the feed rate and the coaxial airflow rate.

The droplets which are atomized can then be allowed to free-fall directly into a reacting bath. The reacting bath cures or sets the hydrogels so that they solidify. Reaction bath curing can be achieved through chemical or non-chemical means. For the case of sodium alginates, calcium ions are used to cross-link the polymer chains. A preferred crosslinker is calcium chloride.

The emulsification method is another technique that can be used for producing hydrogel microbeads. In selecting the continuous phase material, it is preferred that it be immiscible with both the aqueous polymer and oil active.

The matrix-forming material preferably has a range of concentrations usable in practicing the invention. The concentration should be chosen to optimize ease of handling, gelling time, the strength of the hydrogel microbead around the active material droplets. For example, a sodium alginate solution can preferably be prepared in a concentration of about 1 to about 10% (w/v) in water, more preferably about 1.5 to about 5% and most preferably from about 1 to 3%. However, if the hydrogel agent concentration is too great, the solution may be so viscous as to hinder the formation of spherical microbeads.

Alternatively, hydrogel microbeads of the invention can be formed, for example, by adding the matrix forming material solution drop-wise to a selected crosslinker. For example, a method can be used whereby droplet formation and crosslinker addition is completed as a one step process by a vibrating nozzle which
5 ejects a hydrogel droplet from one source and coats the droplet with a crosslinker from another. U.S. Patent No. 4,701,326 teaches use of this method.

In the preferred aspect where alginates are used to immobilize an active material, a crosslinker is preferably made up in solution at a concentration of 1 to 1000 millimolar, more preferably 20 to 500 millimolar and most preferably from
10 50 to 100 millimolar. The concentration ranges may have to be adjusted, depending on the nature of a crosslinker and matrix-forming material.

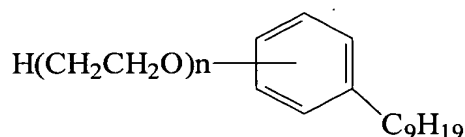
The microbeads comprising matrix material and active material can be treated with the crosslinker solution by soaking, spraying, dipping, pouring or any of several other methods which will deposit an amount of the complexing agent on
15 the droplet. When soaking, the time in solution may be from 1 second to 24 hours, preferably 1 minute to 1 hour, and more preferably from 10 to 30 minutes.

The temperature for hydrogel microbead formation is preferably chosen as to avoid damage or alteration to the active material. For example, in the preferred aspect where alginates are utilized, the temperature is preferably in the range of
20 about 1 °C to about 70 °C; more preferably between about 10 °C to about 40°C, and most preferably between about 15 °C to about 30 °C.

Surfactants can be used in the process of forming the microbeads in effective amounts to enhance droplet formation of the active in the continuous phase of the matrix forming material solution. The incorporation of different
25 surfactants will offer different types of microemulsion drop sizes of the active within the hydrogel as well as dictate the amount of free oil lost in the reacting bath solution. A preferred surfactant has a high critical micelle concentration, such as for example, a product available under the product designation DISPONIL SUS IC 875 (CMC ~ 1%), available from Henkel (Ambler, PA).

Particularly preferred surfactants are nonionic. Examples of suitable surfactants include polyvinylpyrrolidone (PVP) and poly(ethoxy)nonylphenol. PVP is usable and available at various molecular weights in the range of from
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about 20,000 to about 90,000. PVP having a molecular weight of about 40,000 is preferred. Poly(ethoxy)nonylphenols are commercially available under the trade designation IGEPAL from Rhone-Poulenc (Cranbury, NJ), with various molecular weights depending on the length of the ethoxy chain. Poly(ethoxy)nonylphenols having the formula:



where n has an average value from about 9 to about 13 can be used. A preferred poly(ethoxy)nonylphenols is available commercially under the product name IGEPAL 630, from Rhone-Poulenc (Cranbury, NJ) -- 630 is indicative of the approximate molecular weight of the compound. Other examples of suitable surfactants include polyether block copolymers, such as those available under the trade designations PLURONIC and TETRONIC, both available from BASF (Washington, NJ), polyoxyethylene adducts of fatty alcohols, such as BRIJ surfactants available from ICI (Wilmington, DE), and esters of fatty acids, such as stearates, oleates, and the like. Examples of such fatty acids include sorbitan monostearate, sorbitan monooleate, sorbitan sesquioleate, and the like. Examples of the alcohol portions of the fatty esters include glycerol, glucosyl and the like. Fatty esters are commercially available as surfactants under the trade designation ARLACEL C from ICI (Wilmington, DE)

Various properties of the surfactant, such as for example, chain length, functional groups, and hydrophobic regions, can affect the size of the active droplets formed within the microbeads. For example, use of PVP (having a molecular weight of 40,000) tend to result in production of larger sized active droplets than use of poly(ethoxy)nonylphenols (IGEPAL 630).

Ionic surfactants can alternatively be used in the processes of the invention. Examples of suitable ionic surfactants partially neutralized salts of polyacrylic acids such as sodium or potassium polyacrylate or sodium or potassium polymethacrylate.

The active material entrained in the microbeads of the invention are released in air gradually over time. This is in contrast to conventional micro-encapsulated materials that could potentially release the active ingredient nearly all at one time, for example at the time of shell rupture. Active release from the microbeads of the invention has surprisingly been found to be controllable by controlling the humidity (and dryness) of the environment in which the microbeads are in.

While not being bound by this theory, it is believed that the mechanism of release involves water evaporation from the gel and then diffusion of active through the hydrogel matrix. Alternatively, the active may become entrained in the water from the matrix, and as the water evaporates, the active releases into the atmosphere.

In preferred applications, the hydrogel microbeads would be sprayed followed by water evaporation within the gel. As the hydrogel bead dehydrates, the matrix shrinks in size and releases its active with time. The degree of shrinkage of the microbead from its original size, depending on the components used in the formulation. Preferably, the microbeads shrink about 10 to about 90 % from its original size, more preferably from about 40 to about 80 %, and most preferably from about 50 to about 70 %.

Advantageously, the microbead, upon re-exposure to humidity, can swell and rehydrate itself by absorbing water. Re-exposure to humidity can be performed in various ways. For example the microbeads' surfaces can be contacted directly with water or other aqueous solutions. In agricultural applications, a farmer or caretaker can irrigate the plants and foliage to re-hydrate the hydrogel microbeads. Alternatively, the humidity of the environment or ambient air in which the microbeads are located in can be increased by entraining air droplets in the air. Thus, the microbeads can be "re-activated" by re-hydration, thereby selectively controlling the release times of the active material.

The microbeads of the invention can be delivered to an intended substrated by various methods. In the preferred embodiment where the active material is a pheromone, delivery of the microbeads will depend on various factors, such as for example, the size of release coverage desired. For small concentrated areas, the

microbeads can be impregnated into hollow fibres, plastic laminate flakes or twist-ties and then the fibers or ties are physically attached to plants to be protected from insect infestation. For larger areas, spraying (aerially or e.g., by back-pack carried personal spray units) may be the better option.

5 All patents cited in this specification are hereby incorporated by reference.

The following examples are provided to illustrate, but not limit, the scope of the invention. Unless otherwise specified, all parts and percentages are by weight.

10 **EXAMPLES**

The following list of materials were used in the Examples. Listed adjacent to each material is the manufacturer and/or supplier from which the materials were obtained.

3M HFE 7100	3M Co.(St. Paul, MN)
Carvone	Bedoukian (Danbury, CT)
Disponil SUS IC 875	Henkel (Ambler, PA)
Drakeol 34	Penreco (Karns City, PA)
E,E-8,10-C12 alcohol	Shin-Etsu Chemical Co., Ltd. (Tokyo, Japan)
Igepal C0-630	Rhone-Poulenc (Cranbury, New Jersey)
Menthone	Berjé (Bloomfield, NJ)
Paraffin Wax	Aldrich Chemical Co. (Milwaukee, WI)
Sodium alginate	SKW (Lannilis, France)
Solvent 100	Shell Chemical Co. (Bayway, NJ)
Starch	Aldrich Chemical Co. (Milwaukee, WI)
Tixogel EZ100	Süd-Chemie Rheologicals (Louisville, KY)
Z11-C14 acetate	Shin-Etsu Chemical Co., Ltd. (Tokyo, Japan)

15 **TEST METHODS**

To evaluate the physical performance of microbeads of the invention, two parameters were measured: (1) air concentrations of pheromone released from the

microbead formulation and (2) the amount of active remaining (i.e., residual concentration) in the microbead over time.

Air Concentration Determination

5 A known amount of beads (10 microbeads) were recovered and placed in a constant airflow chamber of 100 mL/min (~23-24 °C temperature). The effluent air stream from the chambers was analyzed for active concentration using solid phase microextraction (SPME) (Supelco, Bellefonte, PA) and gas chromatography (GC) (Varian Chromatography Systems, Walnut Creek, CA) over a period of
10 weeks to evaluate the performance of the hydrogel microbeads.

To calculate the Release Rate of an active, the Air Concentration is multiplied by the Air Flow rate.

Residual Concentration Determination

15 Formulations were filtered using a Buchner type vacuum funnel, washed with room temperature distilled water and dried in a fumehood at room temperature for 24 hours. Fifty milligrams of the dried formulation were put on tinfoil squares as application substrates. After the required exposure time, the microbeads were subjected to extraction for at least 24 hours with 4 mL of
20 dichloromethane to determine the residual level of active still remaining in the formulation. Each collected sample was then analyzed by gas chromatography.

EXAMPLE 1

25 For each of the samples A-I, a sodium alginate solution was initially prepared by dissolving a preweighed amount of alginate into a known volume of distilled water. The solution was mixed thoroughly to solubilize the polymer and was deaerated for removal of entrained air bubbles. In a separate 250 mL vessel, the active and surfactant was added and mixed at a speed of about 2000 RPM using a marine type impeller (3.81 cm diameter). To the mixture, the alginate solution
30 was gradually added to form the microemulsion. The emulsion was homogenized for about 30 minutes. The emulsion was then atomized into fine particle droplets using a coaxial air nozzle sprayer. The size of the particles was determined by the

settings on the atomizing device. This involved control of the nozzle head diameter, the feed rate of the emulsion through the nozzle and the airflow which passed along its feed path (shown in Table 2).

5 Samples A-E demonstrated the ability of this invention to encapsulate oils or pheromones with function groups of ketones, alcohols, and acetates. All the formulations resulted in substantially spherical intact hydrogel microbeads containing the desired active.

10 Samples F-H demonstrated the ability of this invention to absorb oils or pheromones with function groups of ketones, alcohols, and acetates within an absorbent material prior to encapsulation within a hydrogel matrix. All the formulations resulted in substantially spherical intact hydrogel microbeads containing the desired active.

15 Sample I incorporated an adhesive material, 3M Microsphere Adhesive Suspension (as described in U.S. Pat. No. 5,508,313, example 2 having a ratio of IOA:AA:Carbowax of 97:2:1) within hydrogel microbeads containing no active material. The addition of adhesive material in the hydrogel formulation allowed the particles to become tacky and sticky when dried.

Table 1: Hydrogel microbead formulations

Sample	Sodium alginate		Active		Surfactant		Calcium conc. (mM)
	Conc. (g/100mL)	Weight (g)	Type	Weight (g)	Type	Weight (g)	
A	2.0	50.0	Carvone	20.0	Igepal CO-630	2.0	50
B	2.0	38.6	E,E-8,10-C12 alcohol/ Solvent 100 (1:4 by wt)	1.0	Disponil SUS IC 875	1.0	50
C	2.5	250.0	Menthone	50.0	Igepal CO-630	5.0	50
D	2.0	38.6	Z11-C14 acetate	1.0	Disponil SUS IC 875	0.4	50
E	2.5	800.0	Z11-C14 acetate	20.0	Igepal CO-630	2.0	1000
F	2.0	40.0	Z11C14 acetate/ starch (1:4 by wt)	3.0	n/a		50
G	2.5	250.0	Menthone/ Tixogel EZ100 (8:1 by wt)	56.0	n/a		50
H	2.5	250.0	Menthone/ parffin wax (10:1 by wt)	44.0	n/a		50
I	2.0	100.0	3M Microsphere Adhesive	10.0	n/a		50

EXAMPLE 2

Hydrogel microbeads were formed using coaxial airflow atomization, using the formulations of Samples A and E. Average particle diameters were measured by evaluating 30-50 microbeads, using a stereomicroscope product name STEREOZOOM 7 available from Bausch & Lomb (Brick, NJ) and a light microscope product LEITZ DIAPLAN available from Ernst Leitz (Wetzlar, West Germany). The nozzle size and settings varied respectively to produce different size particles.

Table 2

Sample	Feed Nozzle		Coaxial air		Mean Diameter (mm)
	Diameter (mm)	Pressure (kPa)	Diameter (mm)	Pressure (kPa)	
A	0.508	68.9	1.17	0	2.8
	0.406	137.9	1.17	0	1.7
	0.508	68.9	1.17	34.5	0.9
	0.406	137.9	1.17	34.5	0.2
E	0.508	34.4	1.40	34.5	0.094
	0.508	110.3	1.40	13.8	0.135
	0.508	110.3	1.40	34.5	0.125
	0.508	96.5	1.40	27.6	0.064

EXAMPLE 3

Following the test methods described above for Air Concentration, the known batches from Sample E of Example 1 were evaluated over a duration of 24 days. Table 3 provides the release rate analysis. Laboratory formulation evaluation studies entailing residual analysis demonstrated that a minimum of four week sustained release of an active (pheromone Z11-C14 acetate) from a hydrophilic matrix (calcium alginate) was achieved. Air Concentration Determination analysis showed a burst of active (pheromone) in the air during the first week of release followed by a gradual decrease with time. Low levels of released pheromone were still being detected from the hydrogel microbeads after 3 weeks

Table 3

Time (days)	Release Rate of Z11-C14 acetate from Example 2, Sample E having 64 μ m dia. (ng/min)
0.00	-
0.04	39.93
0.1	1372.52
3.0	695.26
4.1	325.96
4.8	119.53
6.8	131.27
10.0	95.34
10.9	75.37
17.1	0.10
18.0	0.13
21.0	0.34
24.0	0.22

EXAMPLE 4

The four batches from Example 2 (Formulations from Sample E) were evaluated for Residual Concentration (i.e., amount of active left in the microbead) for 50 days. Table 4 provides the results.

Table 4

Time (days)	% Residual Z11-C14 acetate in hydrogel microbeads formed by Example 2, Formulation SAMPLE E							
	64 microns		94 microns		125 microns		135 microns	
	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD
0	100.0	11.0	100.0	4.0	100.0	17.0	100.0	21.0
2	96.7	6.0	-	-	96.5	28.0	97.9	4.0
10	82.4	11.0	78.2	2.0	44.9	15.0	68.3	11.0
18	60.7	3.0	-	-	24.8	8.0	43.6	13.0
25	56.3	14.0	37.5	7.0	23.6	6.0	47.3	11.0
40	32.0	7.0	26.9	3.0	11.7	4.0	13.5	2.0
47	15.2	1.0	23.1	3.0	4.5	3.0	9.5	5.0

Mean: average of 3 replicates

SD: relative standard deviation of 3 replicates

EXAMPLE 5: Hydrogel encapsulation by emulsification method

For each of Samples J and K, a sodium alginate solution was initially prepared by dissolving a preweighed amount of alginate into a known volume of distilled water. The solution was mixed thoroughly to solubilize the polymer and was deaerated for removal of entrained air bubbles. Active and absorbent were mixed together and allowed to sit overnight. The active/absorbent mixture, surfactant, calcium carbonate, and polymer forming matrix solution were homogenized using a marine type (3.81 cm diameter) impeller at a speed of 1800 RPM for 10 minutes. The emulsion was added to a 1 liter baffled glass reactor containing continuous phase fluid. The mixing impeller was a disk turbine agitator (5.1 cm diameter) and the mixture was emulsified at a speed of about 1800 RPM. After 10 minutes, slow dropwise addition of the pH reducer was commenced to set the gel. The stirring was continued for 10 minutes, then 200 g of a 50 millimolar calcium chloride solution was poured into the reactor and continued mixing for an additional 10 minutes. Discrete spherical microbeads were produced with a particle size range of 4 – 200 microns.

Table 5

Sample	Sodium alginate		Active		Ca CO ₃ weight (g)	Surfactant		Continuous phase		pH reduction
	Conc. (g/100 mL)	Weight (g)	Type	Weight (g)		Type	Weight (g)	Type	Weight (g)	Glacial acetic acid weight (g)
J	2.0	50.0	Carvone/ Tixogel E/Z100 (5: 1)	30.0	0.50	N/A		Drakeol 34	500.0	30.0
K	2.0	25.0	Carvone/ Tixogel E/Z100 (5: 0.6)	28.0	0.25	Span 85	1.0	3M HFE 7100	1000.0	20.0

EXAMPLE 6: Humidity Study

To humidify the airflow entering the flow chamber, a water reservoir was placed in between the airline feed and the flow chamber. As air traveled over the water reservoir, it entrained moisture thus humidifying the airflow. The humidity level under normal room conditions ranged from 20-30% relative humidity. Under water entrained conditions, the relative humidity level of the air in the chambers ranged from 40 – 95%.

For the humidity study, an active, carvone, was used to model the release from calcium alginate hydrogel microbeads. FIG. 2 shows the amount of active released by the microbeads, as measured using the Air Concentration Determination Test described above. As shown in FIG. 2, from microbeads of the Sample J formulation, the initial release was observed followed by a constant release with time. In the presence of humidity regions 20 and 22, the hydrogels absorbed the moisture from the air and released more active contained within the matrix. This shrink/swell behavior was found to be cyclical, depending on whether the air was dry or humid.